

APPENDIX F

REVIEW OF SCIENTIFIC INFORMATION



REVIEW OF SCIENTIFIC INFORMATION

By GORDON REEVES, Ph.D.

March 20, 2003

The Aquatic Conservation Strategy (ACS) of the Northwest Forest Plan is designed to restore and maintain the process that create and maintain conditions in aquatic ecosystems over time across the area inhabited by the northern spotted owl (*Strix occidentalis caurina*). The ACS is a region-wide strategy designed to restore and protect the ecological processes and landforms that contribute habitat elements to streams and to promote the favorable ecological conditions for fish and other aquatic and riparian-dependent organisms (FEMAT 1993). The ACS was based on the best science available at the time.

Much scientific literature on aquatic ecosystems, on the impact of human activities on them, and on conservation strategies for fish and other aquatic and riparian organisms has been produced since FEMAT in 1993. This document summarizes key science findings on the topics of: (1) ecosystem and landscape dynamics and the range of natural variation (RNV); and (2) the ecological role of headwater streams. These are key topics that relate to ACS components and they are particularly relevant to the changes proposed by the Draft Supplemental Environmental Impact Statement. This document synthesizes some of the key peer-reviewed literature on these topics. However, it does not summarize or review all of the scientific literature about the topics listed previously or about other components of the ACS. Documents that provide excellent reviews and synthesis on these and other relevant topics include Spence et al. (1996), National Research Council (1996), Naiman and Bilby (1998), Gresswell (1999) and Everest and Reeves (in review).

Spatial and Temporal Scales and Disturbance

General Review

Prior to the development of the ACS, much of the focus for fish was on relatively small spatial scales, such as habitat units (Bisson et al. 1982, Nickelson et al. 1992) and reaches (Murphy and Koski 1989). Williams et al. (1989) found that no fish species listed under that Endangered Species Act was ever recovered after listing. They attributed this to the general failure of recovery efforts to focus on habitat attributes rather than on the restoration and conservation of ecosystems.

The ACS is focused at the ecosystem and landscape levels and developed for application over broad geographic areas. This was necessary to aid in the recovery of freshwater habitats of listed and declining populations of anadromous salmon and trout (*Oncorhynchus* spp.) and other fish within the range of the northern spotted owl. Since the ROD, a variety of sources, including interested publics, interest groups, scientific review and evaluation groups (e.g., National Research Council 1996, Independent Multidisciplinary Scientific Team 1999), regulatory agencies, and policy- and decision-

makers have called for the development of policies and practices to manage the freshwater habitats of at-risk fish at ecosystem and landscape levels.

Our understanding of what constitutes the aquatic ecosystem and the landscape they occupy, particularly with regards to anadromous salmon and trout that are the major focus of ACS, has evolved since the ROD. Ecosystems and landscapes are different entities and therefore, have different management requirements. Ecosystems are vague entities with boundaries that may shift with space and time. Reeves et al. (2002) and Reeves et al. (in press-a) considered the watershed, which was defined as subbasins of 20-200 square miles by FEMAT (1993), to be the boundaries of an aquatic ecosystem. This delineation is consistent with the size criteria and definition of ecosystems of Hunter (1996). A landscape is a mosaic or collection of ecosystems (Hunter 1996) that occupy a relatively large area (2.47×10^5 to 2.47×10^7 acres (Concannon et al. 1999)). From an aquatic perspective, multiple watersheds that are contiguous are considered a landscape (Reeves et al. 2002, Reeves et al. in press-a).

Major paradigms of ecosystem management include (Lugo et al. 1999):

- (1) Ecosystems are not steady state but are constantly changing through time.
- (2) Ecosystems should be managed from the perspective of resilience, as opposed to stability.
- (3) Disturbance is an integral part of any ecosystem and is required to maintain ecosystems.

Ecologists (Holling 1973, White and Pickett 1985) and managers recognize the dynamic nature of terrestrial ecosystems and how the associated biota and physical characteristics change through time. They are also aware that range of conditions that an ecosystem experiences is determined to a large extent by the disturbance it encounters (e.g., wildfire, hurricane, timber harvest and associated activities, etc.). Natural disturbances can: (1) increase biological diversity; (2) be crucial for the persistence of some organisms and the habitat that support them; and (3) express and maintain key ecological processes (Turner et al. 1994).

Resilience is the ability of an ecosystem to recover to pre-disturbance conditions following a disturbance (Lugo et al. 1999). An ecosystem demonstrates resilience after a disturbance when the environmental changes caused by the disturbance are within the range of range of conditions that that the system experienced before disturbance (See discussion of range of natural variability that follows). Reduced resilience may include extirpation of some species, increases in species favored by available habitats (Levin 1974, Harrison and Quinn 1989, Hansen and Urban 1992).

The less management actions resemble the natural disturbance regime under which an ecosystem evolved, the less resilient an ecosystem will be. Thus, the obvious challenge for ecosystem management is to make management actions resemble the natural disturbance regime as closely as possible (Lindenmayer and Franklin 2002). Factors that should be considered in developing ecosystem management plans and policies include frequency, magnitude (White and Pickett 1985, Hobbs and Huenneke 1992) and legacy

(i.e., the conditions and materials that exist immediately following the disturbance) (Reeves et al. 1995, Lindenmayer and Franklin 2002) of disturbance regimes in managed ecosystems. The impact on the ecosystem will depend on how closely the management disturbance regime resembles the natural disturbance regime with regard to these factors. Everest and Reeves (in review) reported that they found no evidence in the peer-reviewed literature where fish populations or habitat responded positively to or remained unchanged as a result of the impacts from intensive land management activities.

Landscape management strives to maintain a variety of ecological states in some desired spatial and temporal distribution. To do this, landscape management must consider: (1) the development of a variety of conditions or states in individual ecosystems with the landscape at any point in time; and (2) the pattern resulting from the range of ecological conditions that are present (Gosz et al. 1999). Management should address the dynamics of individual ecosystems, the external factors that influence the ecosystems that compromise the landscape, and the dynamics of the aggregate of ecosystems (Concannon et al. 1999).

To establish a dynamic perspective of ecosystems and landscapes, the range of natural variability (RNV) must be recognized. RNV is the range of conditions that a spatial level of organization experiences naturally over an extended time period, several decades to centuries. It is often used for individual components of an ecosystem, such as number of pieces of large wood or number of pools, or for ecological states. The usual manner for establishing the RNV for a parameter is to measure the parameter in pristine systems (i.e., systems having little or no history of impact from human activities). The RNV is represented by the range of these values. This is well established for terrestrial systems (i.e., early-, mid-, and late-successional) (e.g., Wimberly et al. 2000) but not nearly well or widely recognized for aquatic ecosystems.

Spatial scale is an important, but not well recognized, element of RNV. The RNV is inversely related to spatial scale (Wimberly et al. 2000). The smaller the spatial scale, the larger the RNV and, conversely, the larger the scale the smaller the RNV. Hierarchy theory provides the rationale for this relation and is an appropriate framework for considering ecosystem issues at and between different spatial scales (Overton 1977). Each level within the hierarchy of an ecosystem has unique properties and behaviors that are expressed over time. The properties of lower levels of organization are “averaged, filtered, and smoothed” as they are aggregated at higher levels of organization (O’Neill et al. 1986). Consequently, the range and variability in the properties and conditions of the system are relatively wide at lower levels of organization compared to higher levels (Wimberly et al. 2000). A recent paper on the concept of RNV (Landres et al. 1999) and another estimating RNVs (Keane et al. 2002) did not consider the effect of spatial scales stimulations.

Wimberly et al. (2000) illustrated the RNV of successional vegetative stages in the Oregon Coast Range at the various spatial scales. They estimated (based on a model of fire frequency and intensity and vegetation response over 3000 years) that at the scale of a late successional reserve (100,000 acres) the range in the amount of old growth was

from 0 to 100%. For an area roughly the size of a national forest (750,000 acres), the RNV for old growth was from approximately 10 to 75%. The RNV for the Coast Range (5,600,000 acres) was 30-55%.

The following example can be used to further explain the reason for the relation between RNV and spatial scale. Assume that a person is suspended in a balloon above a given area in the Oregon Coast Range for several decades to centuries and is able to observe the changes in the age of trees, similar to what Wimberly et al. (2000) did with their model. There is a very high likelihood that the sites will be disturbed at some point in time by wildfire, a windstorm, or other infrequent disturbance event. Immediately following the event there will be no older trees; they will have been killed by the event. Assuming that the next large disturbance event will not occur for some time, new trees will grow and eventually the entire area will be covered with old trees. The RNV is 0 to 100% for at this scale.

A different pattern would be observed if the balloon was suspended at a higher altitude and a larger area was observed. The large, infrequent disturbance events generally affect relatively small portions of the landscape at any one time. Thus, it is very unlikely that the entire area being observed would be affected by a disturbance event at the same time. The asynchronous nature of the disturbance events results in a series of patches of vegetation of different ages. This narrows the RNV because of the reduce likelihood of finding the extreme condition of the entire area either had no old growth or all of it was old growth at any point in time. The RNV is further reduced at larger spatial scales because disturbance events are even more desynchronized.

Dynamics and Aquatic Ecosystems

The perspective that aquatic systems are dynamic, particularly at the ecosystem and landscape scale, was not widely recognized at the time that the ACS was developed. Prior to the development of the ACS, there was recognition that biotic (Resh et al. 1988) and physical (Swanson et al. 1988) components of aquatic systems, particularly at the smaller spatial scales, were influenced by relatively frequent events, such as floods. One reason for the absence of the recognition of dynamics of aquatic ecosystems is that the major paradigms that shape our thinking about aquatic systems, such as the River Continuum Concept (Vannote et al. 1980), do not consider time or its influence. Similarly, classification schemes such as that of Rosgen (1994) identify a single set of conditions for a given stream or reach type; no consideration is given as to how these conditions may vary over time. The physical and biological relations were assumed to be fixed in time and to be unchanging. Frissell et al. (1986) describe the hierarchical organization nature and identify a temporal component associated with each level; the finer the scale, the shorter the response period. However, they did not consider how features of a given level in the hierarchy respond over time. A more recent examination of the hierarchical organization of streams by Fausch et al. (2002) also recognized that time is a critical factor to consider when examining aquatic ecosystems. However, they did not integrate it into their description of stream systems. Failure to incorporate time into consideration of aquatic systems, especially at higher levels of organization, has led

to an implied expectation that stream ecosystems experience a limited, if not single, set of conditions and that this condition (or conditions) is relatively stable through time.

The foundation for the focus on ecological processes and dynamics of the ACS came from Naiman et al. (1992). They hypothesized that different parts of a watershed (i.e., headwaters, middle portion, lower portion) had different disturbance regimes, based on frequency and magnitude of disturbance. They also believed that the landscape would have watersheds with range of conditions because of the asynchronous nature of large and infrequent disturbance events, such as wildfire and flooding. Since then a number of studies examined the dynamics of aquatic ecosystems in space and time since the ACS. Reeves et al. (1995) described the range of conditions of watershed in the Tyee sandstones of the central Oregon coast in response to wildfire. They found a range of conditions from less productive to more productive. May (2001) did this for headwater streams in the same region and found a wide variation in conditions within a channel and between channels. Channels that had not been disturbed for several decades were filled with gravel and wood. Recently disturbed channels were devoid of sediment and wood and were scoured to bedrock. Benda and Dunne (1997a,b) and Benda et al. (1998) described a similar distribution of in-channel sediment conditions in watersheds over time. Benda et al. (in press-a) examined the impact of landslides following wildfires on aquatic ecosystems in the Boise River, Idaho. The landslides had significant impacts on the channel, creating complex channels and delivering large amounts of wood to the channel. These conditions are expected to vary widely over time.

The following from Reeves et al. (1995) is a synopsis of the long-term response of aquatic ecosystems to disturbances and an illustration of the concept of the RNV at the watershed scale. Reeves et al. (1995) examined three watersheds in the central Oregon Coast Range that were at different points of time from the last major wildfire and catastrophic hillslope failure. The most recently disturbed watershed (80-100 years since the last major fire and hillslope failure) and the one that had not been disturbed for an extended time (300 years) had the simplest, and least favorable fish, habitat. However, the specific habitat attributes varied between these watersheds. The most recently disturbed watershed had large amount of gravel and a relatively low abundance of large wood. The system that was the furthest from disturbance had just the opposite, little to no gravel and an abundance of large wood. The watershed that was intermediate in time from disturbance (160-180 years) had intermediate levels of gravel and wood and the most favorable conditions for fish. The numbers and diversity of juvenile salmon and trout was greater in this watershed than in the others.

Recent studies examined how that aquatic ecosystems at the site and reach scale respond to landslides and/or floods. Hogan et al. (1998) examined the impacts of landslides from timber harvest activities on streams in the Queen Charlotte Islands, British Columbia. In-channel features changed immediately following the landslide. Upstream of a deposit, pools were lost and smaller sediments accumulated in riffles. Downstream the channel gradient steepened and the amount of gravel declined. Over time, 10-50 years depending on site-specific features and conditions, more complex and diverse conditions for fish developed.

Studies in the Appalachian Mountains of Virginia examined the impacts of floods and landslides. Dolloff et al. (1994) examined changes in biological and habitat conditions in a small stream following flooding associated with Hurricane Hugo. There was no change in the total area of riffles and pools but the total number of habitat units declined and their mean depth decreased. The amount of large wood in the channel doubled. No fish species were lost from the system but the numeric response varied. Some species increased in abundance and others declined.

In Shenandoah National Park, physical and biological features of a stream that experienced flooding and a debris flow varied over five years of study (Roghair et al. 2002). Immediately following the debris flow and flood, the number of pools and riffles and substrate size increased and pool and riffle surface area decreased. Five years later, the total number of pools was at level found before the flood and debris flows and substrate size decreased. The density of brook trout (*Salvelinus fontinalis*) four years after the flood and debris flow exceeded the pre-event level. It declined to pre-event levels in the fifth year.

Several factors influenced the responses of the studies that were just discussed. The physical legacy of the disturbances was important. Wood and sediment are the basic building blocks of fish habitat. These materials were introduced into the streams and allowed for the development of conditions favorable to fish over time. The presence of refugia is an important determinant of how fish respond to disturbances (Sedell et al. 1990). A refugia can be an area that afforded protection to individuals during the disturbance event and is the affected area or it could be a nearby area that was not affected. Refugia provide sources of individual to re-establish populations in affected areas. Additionally, the life history (Dolloff et al. 1994) and habitat requirements (Reeves et al. 1993, Reeves et al. 2002) can influence the immediate and longer-term response of a species to disturbance events.

Implications

Focusing policies for and management of aquatic ecosystems at the landscape scale presents challenges to policy makers, managers, and regulators (Reeves et al. 2002). One major task is to understand how the condition of aquatic ecosystems varies through time at all spatial scales and the ecological, social, and economic implications of this variation. Currently, the natural range of the condition of aquatic ecosystems is assumed to be small and to generally be good with regards to habitat. This condition is expected to be relatively constant through time and to be present on all systems at the same time. Assuming that this expectation can simply be applied to higher spatial levels is at least partially responsible for the current misunderstanding about the ACS. Focusing on the landscape requires an understanding that conditions in aquatic systems vary over time at each spatial scale. It also requires that appropriate goals and objectives be established for the landscape. In the case of aquatic ecosystems and watershed, this will require identifying what is the appropriate fraction of the watershed that should be in “good” condition at any point in time. Also, it requires the articulation of policies that recognize

the dynamic nature of aquatic ecosystems and describe practices that allow the systems to express a range of desired conditions over time.

The dynamic view of aquatic ecosystems and landscapes described in the previous paragraph is not uniformly held or recognized in the scientific community. Montgomery et al. (2003) questioned the role that dynamics plays in unmanaged situations. They contend that the role of disturbances such as debris flows in old-growth forests is limited. They believed that models of disturbance ecology for salmonids, such as that presented by Reeves et al. (1995), need to recognize differences in the disturbance dynamics of old growth and industrial forests. This is necessary to “provide credible avenues for determining risk associated with land management in steep forested terrain” (Montgomery et al. 2003 p. 87). They felt that “management recommendations based on evolutionary interpretations that are themselves based on a disturbance model primarily applicable to industrial forests may prove misleading” (Montgomery et al. 2003 p. 87).

It is imperative that the spatial scale be specified when RNV and cumulative effects are discussed or evaluated. At small scales the RNV is very large. Consequently, it could be argued that there would be no cumulative effects resulting from management actions, except from the most extreme impacts. Most assessments of the impacts of human activities are made at relatively small scales. Failure to recognize the relation between space and RNV undoubtedly contributed to the current confusion about the ACS and the scales at which it is applied and how compliance is measure.

Also, understanding the relation between different spatial scales is necessary to successfully assess the effects of management policies and activities aquatic ecosystems in the future. The failure to articulate or to recognize this relation contributes to the often intense and divisive debate about management policies and practices and impedes the development of viable options for managing aquatic ecosystems. Shifting the focus to landscape levels will require recognition of the principles about hierarchy theory and the relation among levels of organization if future management and assessment policies are to be successful.

Headwater streams

The establishment of Riparian Reserve was one of the cornerstones of the ACS. The Riparian Reserve network included fish-bearing streams, which had been the focus of management of aquatic ecosystems prior to FEMAT, as well as small, fishless headwater streams. The latter generally comprise the vast majority of the stream network (Gomi et al. 2002). Prior to the ACS these were not widely recognized as part of the aquatic ecosystem. Knowledge and recognition of the ecological importance of headwater streams has increased since the ACS was first articulated. They are sources of sediment (Benda and Cundy 1997a,b, Zimmerman and Church 2001) and wood (Reeves et al. in press-b) for fish bearing streams. They provide habitat for several species of native amphibians (Kelsey and West 1998) and macroinvertebrates (Meyer and Wallace 2001) (including recently discovered species (Dieterich and Anderson 2000)) and may be

important sources of food for fish (Wipfli and Gregovich 2002). Small streams are also storage and processing sites of nutrients and organic matter, which are important components of the energy base for organisms used by fish for food (Wallace et al. 1995, Webster et al. 1999, Kiffney et al. 2002, Wipfli and Gregovich 2002).

Headwater streams are among the most dynamic portions of the aquatic ecosystems (Naiman et al. 1992). Tributary junctions between headwater streams and larger channels are important nodes for regulating material flows in a watershed (Gomi et al. 2002) and are the locations where site level impacts from management activities are often observed. These locations have unique hydrologic, geomorphic, and biological attributes. The movement of sediment, wood, and other materials through these locations result in sites of high biodiversity (Minshall et al. 1985, Johnson et al. 1995). Habitat in these sites may also range from simple to complex depending on time from the disturbance (e.g., landslides and debris flows) and the types and amount of materials delivered to the channel.

Large wood is an important element of stream and river ecosystems. It forms and influences the size and frequency of habitat units for fish and other aquatic and riparian-dependent organisms (Bilby and Ward 1989, Wallace et al. 1995, Bilby and Bisson 1998). The size pieces and amount of wood in the channel also influences the abundance, biomass, and movement of fish (Murphy et al. 1985, Fausch and Northcote 1992, Harvey and Nakamoto 1998 Harvey et al. 1999, Roni and Quinn 2001).

Wood enters streams via chronic and episodic processes (Bisson et al. 1987). Chronic processes, such as tree mortality and bank undercutting (Grette 1985, Murphy and Koski 1989, Bilby and Bisson 1998), generally introduce single pieces or relatively small numbers of trees at frequent time intervals. Episodic processes usually add large amounts of wood to streams in large but infrequent events such as wind throw (Harmon et al. 1986), wildfire (Agee 1993), severe floods, and landslides and debris flows (Keller and Swanson 1979, May 2002, Reeves et al. in review).

Examinations of wood sources in streams (e.g., Murphy and Koski 1989, McDade et al. 1990, Robison and Beschta 1990) have focused on chronic input from immediately adjacent riparian zone. Such studies found that the vast majority of wood found in streams was derived from within a distance equal to the height of streamside trees. These and other studies (e.g., Van Sickle and Gregory 1990) either did not consider episodic sources of wood or found that they were only a small proportion of the total input (Murphy and Koski 1989).

In steep terrain, which is found on much of the area covered by the Northwest Forest Plan, landslides and debris flows are potentially important mechanisms for delivering sediment and wood from hillslopes and small headwater channels to valley-bottom streams. Reeves et al. (in press-b) found that an estimated 65% of the number of pieces and 46% of the total volume of wood in a pristine watershed in coastal Oregon came from outside the riparian zone immediately adjacent to the fish-bearing stream. Over 80% of the total number of pieces of wood in a western Washington (Benda et al. in

review) and northern California stream (Benda et al. in press-b) were from upslope sources. Other studies, such as May (2002) and Benda et al. (in press-a), found large amounts of wood from upslope sources in streams in the Oregon Coast Range and Idaho, respectively.

Pieces of large wood delivered from upslope areas are generally smaller than those originating from the riparian zones along fish-bearing streams. Reeves et al. (in review) found that the mean volume of a piece of large wood from upslope areas was one third the mean size of pieces from stream adjacent riparian areas in a coastal Oregon stream. Differences in mean size is likely attributable to fire history and other stand-resetting events. Hillslopes are more susceptible to fire and burn more frequently than streamside riparian zones (Agee 1993). Thus, trees in the streamside riparian zone may be disturbed less frequently and achieve larger sizes than upslope trees.

Geomorphic features of a watershed influence the potential contribution of upslope wood sources. Steeper, more highly dissected watersheds will likely have a greater proportion of wood coming from upslope sources than will watersheds with lower gradients. Murphy and Koski (1989) and Martin and Benda (2001) found that upslope sources of wood comprised a relatively small proportion of the wood in streams that they examined in Alaska. The watershed studied by Martin and Benda (2001) had a wide valley floor so wood was deposited along valley floors, away from the main channel. In contrast, Benda et al. (in press-a) found that wood delivered in landslides following wildfires was deposited in wide valley reaches in the Boise River, Idaho. In a central Oregon coast stream, Reeves et al. (in press) found that the amount of upslope-derived wood was greatest in reaches with narrow valley floors.

Even in watersheds where the potential contribution from upslope sources of wood is high, the ability of individual upslope sources of wood to fish-bearing streams can vary widely. Benda and Cundy (1990) identified the features of first and second order channels with the greatest potential to deliver materials to fish-bearing streams in the central Oregon coast. The primary features were gradients of 8-10% with tributary junction angles of $<45^\circ$. These features can be identified from Digital Elevation Models (DEMs) and topographic maps.

Literature Cited

- Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.
- Benda, L.E. 1994. Stochastic geomorphology in a humid landscape. Ph.D. dissertation. University of Washington, Seattle, Washington.
- Benda, L.E., C. Veldhuisen, and J. Black. in review. Influence of debris flows on the morphological diversity of channels and valley floor, Olympic Peninsula, Washington. Geological Society of America Bulletin.
- Benda, L.E., D. Miller, P. Bigelow, and K. Andras. in press-a. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management
- Benda, L.E., D.J. Miller, T. Dunne, G.H. Reeves, and J.K. Agee. 1998. Dynamic landscape systems. Pages 261-288. *in* R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer, New York
- Benda, L.E., P. Bigelow, and W. Worsley. in press-b. Recruitment of in-stream large wood in old-growth and second-growth redwood forests, northern California, U.S.A. Canadian Journal of Forest Research
- Benda, L.E., and T. Dunne. 1997a. Stochastic forcing of sediment supply to the channel networks from landsliding and debris flows. Water Resources Research 33:2849-2863.
- Benda, L.E., and T. Dunne. 1997b. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research 33:2865-2880.
- Benda, L.E. and T.W. Cundy. 1990. Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal 27:409-417.
- Bilby, R.E. and J.W. Ward. 1989. Changes in characteristics and functions of large woody debris with increasing size of streams in southwestern Washington. Transactions of the American Fisheries Society 118:368-378.
- Bilby, R.E. and P.A. Bisson. 1998. Function and distribution of large woody debris. Pages 324-346. *in* R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York.
- Bisson, P.A., R.E. Bilby, M.D. Byrant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested

- streams in the Pacific Northwest: past, present, and future. Pages 143-190. *in* E.O. Salo and T.W. Cundy, editors. Streamside management and fishery interactions. Institute of Forest Resources. University of Washington, Seattle, Washington.
- Berg, D.R. 1995. Riparian silvicultural system design and assessment in the Pacific Northwest Cascade Mountains, U.S.A. *Ecological Applications* 5:87-96.
- Bisson, P.E., J.L. Nielson, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62-73. *in* N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Western Division, American Fisheries Society. Portland, Oregon.
- Brosfokske, K.D., Chen, J., Naiman, R.J., and Franklin, J.F. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. *Ecological Applications* 7:1188-1200.
- Concannon, J.A., C.L. Shafer, R.L. DeVelice, R.M. Sauvajot, S.L. Boudreau, T.E. Demeo, and J. Dryden. 1999. Describing landscape diversity: a fundamental tool for landscape management. Pages 195-218. *in* R.C. Szaro, N.C. Johnson, W.T. Sexton, and A.J. Malick, editors. Ecological stewardship: a common reference for ecosystem management, volume II. Elsevier Science, Ltd., Oxford, United Kingdom.
- Dieterich, M. and N.H. Anderson. 1998. Dynamics of abiotic parameters, solute removal sediment retention in summer-dry headwater streams of western Oregon. *Hydrobiologia* 379:1-15.
- Dieterich, M. and N.H. Anderson. 2000. The invertebrate fauna of summer-dry streams in western Oregon. *Archive fur Hydrobiologie* 147:273-295.
- Dolloff, C.A. and P.A. Flebbe. 1994. Fish habitat and fish populations in a southern Appalachian watershed before and after Hurrican Hugo. *Transactions of the American Fisheries Society* 123: 668-678.
- Everest, F.H. and G.H. Reeves. in review. Riparian and aquatic habitats in the Pacific Northwest and southeast Alaska: management history and alternative management strategies. General Technical Report. USDA Forest Service, Pacific Northwest Research Station. Portland, Oregon.
- Fausch, K.D. and T.G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 682-693.

- Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li . 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *BioScience* 52: 483-498.
- Forest Ecosystem Management Assessment Team (FEMAT). Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team. U.S. Government Printing Office 1973-793-071. U.S.D.A. Forest Service, U.S.D.I. Fish and Wildlife Service, Bureau of Land Management, and Park Service, U.S. Department of Commerce, National Oceanic and Atmospheric Administration and National Marine Fisheries Service, and U.S. Environmental Protection Agency. Portland, Oregon.
- Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* 10: 199-214.
- Gomi, T., R.C. Sidle, and J.S. Richardson. 2002. Understanding processes and downstream linkages of headwater streams. *BioScience* 52:905-916.
- Gosz, J.R., J. Asher, B. Holder, R. Knight, R. Naiman, G. Raines, P. Stine, and T.B. Wigley. 1999. An ecosystem approach for understanding landscape diversity. Pages 157-194. *in* R.C. Szaro, N.C. Johnson, W.T. Sexton, and A.J. Malick, editors. *Ecological stewardship: a common reference for ecosystem management*, volume II. Elsevier Science, Ltd., Oxford, United Kingdom.
- Grette, G.B. 1985. The abundance and role of large organic debris in juvenile salmonid habitat in streams in second growth and unlogged forests. M.Sc. thesis, University of Washington, Seattle, Washington.
- Gresswell, R.E. Fire and aquatic ecosystems in forested biomes of North America. *Transactions of the American Fisheries Society* 128: 193-221.
- Hansen, A.J. and D.L. Urban. 1992. Avian response to landscape patterns: the role of species life histories. *Landscape Ecology* 7: 163-180.
- Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate streams. *Advances in Ecology* 15: 133-302.
- Harrison, S. and J.F. Quinn. 1989. Correlated environments and the persistence of metapopulations. *Oikos* 56:293-298.
- Harvey, B.C., R.J. Nakamoto, and I.L. White. 1999. Influence of large woody debris and bankfull flood on movement of adult resident coastal trout (*Oncorhynchus clarki*)

- during fall and winter. Canadian Journal of Fisheries and Aquatic Sciences 56: 2161-2166.
- Harvey, B.C. and R.J. Nakamoto. 1998. The influence of large wood debris on retention, immigration, and growth of coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) in stream pools. Canadian Journal of Fisheries and Aquatic Sciences 55:1902-1908.
- Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservations. Conservation Biology 6: 324-337.
- Hogan, D.L., S.A. Bird, and S. Rice. 1998. Stream channel morphology and recovery processes. Pages 77-96. in D.L. Hogan, P.J. Tschaplinski, and S. Chatwin, editors. Carnation Creek and Queen Charlotte Islands fish/forestry workshop: applying 20 years of coast research to management solutions. Land management handbook. Crown Publications, Inc., Victoria, British Columbia.
- Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4: 1-23.
- Hunter, M.L. 1996. Fundamental of Conservation Biology. Blackwell Scientific, Cambridge, Massachusetts
- Independent Multidisciplinary Scientific Team. 1999. Recovery of wild salmonids in western Oregon forests: Oregon Forest Practices Act rules and the measures in the Oregon Plan for salmon and watersheds. Technical Report 1999-1 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resource Office, Salem, Oregon.
- Johnson, B.L., W.B. Richardson, and T.J. Naimo. 1995. Past, present, and future concepts in large river ecology. BioScience 45:134-141.
- Keane, R.E., R.A. Parsons, and P.F. Hessberg. 2002. Estimating historical range and variation of landscape patch dynamics: limitations of the simulation approach. Ecological Modeling 151:29-49.
- Keller, E.A. and Swanson, F.J. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380.
- Kelsey, K.A. and S.D. West. 1998. Riparian wildlife. Pages 235-260. in R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York.
- Kiffney, P.M., J.S. Richardson, and M.C. Feller. 2000. Fluvial and epilithic organic material dynamics of headwater streams of southwestern British Columbia, Canada. Archive fur Hydrobiologie 148:109-129.

- Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9: 1179-1188.
- Levin, S. 1974. Dispersion and population interactions. *American Naturalist* 108: n207-228.
- Lindenmeyer, D.B. and J. F. Franklin. 2002. Conserving forest biodiversity: a comprehensive multiscale approach. Island Press, Washington.
- Lugo, A.E., J.S. Baron, T.P. Frost, T.W. Cundy, and P. Dittberner. 1999. Ecosystem processes and functioning. Pages. 219-254. *in* R.C. Szaro, N.C. Johnson, W.T. Sexton, and A.J. Malick, editors. *Ecological stewardship: a common reference for ecosystem management*, volume II. Elsevier Science, Ltd., Oxford, United Kingdom.
- Martin, D.J. and L.E. Benda. 2001. Patterns of instream wood recruitment and transport at the watershed scale. *Transactions of the American Fisheries Society* 130:940-958.
- May, C.L. 2001. Spatial and temporal dynamics of sediment and wood in headwater streams in the central Oregon Coast Range. Ph.D. dissertation. Oregon State University, Corvallis, Oregon.
- May, C.L. 2002. Debris flows through different forest age classes in the central Oregon Coast Range. *Journal of the American Water Resources Association* 38: 1-17.
- McDade, M.H., F.J. Swanson, W.A. McKee, J.F. Franklin, and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Can. J. For. Res.* 20: 326-330.
- Meyer, J.L. and J.B. Wallace. 2001. Lost linkages and lotic ecology: Rediscovering small streams. Pages 295-317. *in* Press, M.C., N.J. Huntley, and S. Levin, editors. *Ecology: Achievements and Challenge*. Blackwell Scientific. Oxford, United Kingdom.
- Minshall, G.W., K.W. Cummins, R.C. Peterson, C.E. Cushing, D.A. Burns, J.R. Sedell, and R.L. Vannote. 1985. Development in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1045-1055.
- Montgomery, D.R., T.M. Massong, and S.C.S. Hawley. 2003. Influence of debris flows and log jams on the location of pools and alluvial channel reaches, Oregon Coast Range. *Geological Society of America Bulletin* 115:78-88.

- Murphy, M.L. and K.V. Koski. 1989. Input and depletion of coarse woody debris in Alaska streams. *North American Journal of Fisheries Management* 9:427-436.
- Murphy, M.L., K.V. Koski, J. Heifetz, S.W. Johnson, D. Kirchofer, and J.F. Thedinga. 1985. Role of large organic debris as winter habitat for juvenile salmonids in Alaska streams. *Proceedings Western Association of Fish and Wildlife Agencies* 1984: 251-262.
- Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. McDonald, M.D. O'Conner, P.L. Olson, and E.A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. Pages 127-188. *in* R.J. Naiman, editor. *Watershed management: balancing sustainability and environmental change*. Springer-Verlag, New York.
- Naiman, R.J. and R.E. Bilby, editors. 1998. *River ecology and management: lessons from the Pacific coastal ecoregion*. Springer. New York. 705 pages.
- National Research Council. 1996. *Upstream: salmon and society in the Pacific Northwest*. National Academy Press. Washington, D.C. 452 pages.
- Nickelson, T.E., J.D. Rodgers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences* 43:527-535.
- O'Neill, R.V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen. 1986. A hierarchical concept of ecosystems. *Monographs in Population Biology* 23. Princeton University Press, Princeton, New Jersey.
- Overton, W.S. 1977. A strategy for model construction. Pages 50-73. *in* C.A.S. Hall and J.W. Day, editors. *Ecosystem modeling in theory and practice: an introduction with case histories*. John Wiley and Sons, New York.
- Pess, G.R., D.R. Montgomery, E.A. Steel, R.E. Bilby, B.E. Feist, and H.M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 59:613-623.
- Petranka, J.W., M.E. Eldridge, and K.E. Haley. 1993. Effects of timber harvesting on southern Appalachian salamanders. *Conservation Biology* 7:363-370.
- Reeves, G.H., D.B. Hohler, D.P. Larsen, D.E. Busch, K. Kratz, K. Reynolds, K.F. Stein, T. Atzet, P. Hays, and M. Teehhan. in press-a. Aquatic and riparian effectiveness monitoring plan for the Northwest Forest Plan. PNW-GTR 577. USDA Forest Service, PNW Research Station. Portland, Oregon.

- Reeves, G.H., F.H. Everest, and J.R. Sedell. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. *Transactions of the American Fisheries Society* 122:309-317.
- Reeves, G.H., K.M. Burnett, and E.V. McGarry. in press-b. Sources of large wood in a pristine watershed in coastal Oregon. *Canadian Journal of Forest Research*.
- Reeves, G.H., K.M. Burnett, and S.V. Gregory. 2002. Fish and aquatic ecosystems in the Oregon Coast Range. Pages 68-98. *in* Hobbs, S.D., J.P. Hayes, R.L. Johnson, G.H. Reeves, T.A. Spies, J.C. Tappeiner II, and G.E. Wells, editors. *Forest and stream management in the Oregon Coast Range*. OSU Press, Corvallis, Oregon.
- Reeves, G.H., L.E. Benda, K.M. Burnett, P.A. Bisson, and J.R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. *in* J. Nielsen, editor. *Evolution in the aquatic ecosystem: defining unique units in population conservation*. American Fisheries Society Symposium 17. Bethesda, Maryland.
- Resh, V.H. A.V. Brown, A.P. Covich, M.E. Gurtz, H. W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J. B. Wallace, and R. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7: 433-455.
- Robison, E.G. and R.L. Beschta. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1684-1693.
- Roghair, C.N., C.A. Dolloff, and M.T. Underwood. 2002. Response of a brook trout population and instream habitat to catastrophic flood and debris flow. *Transactions of the American Fisheries Society* 131: 718-730.
- Roni, P. and T.P. Quinn. 2001. Density and size of juvenile salmonid in response to placement of large woody debris in western Oregon and Washington. *Canadian Journal of Fisheries and Aquatic Sciences* 58:282-292.
- Rosgen, D.L. 1994. A classification of natural rivers. *Catena* 22: 169-199.
- Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. Role of refugia in recovery from disturbances: modern fragmented and disconnected landscapes. *Environmental Management* 14:711-724.
- Spence, B.C., G.A. Lomnický, R.M. Hughes, and R.P. Novitzki. 1986. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp. Corvallis, Oregon. 356 pages.

- Swanson, F.J., T.K. Kratz, N. Caine, and R.G. Woodmansee. 1988. Landform effects on ecosystem patterns and processes. *BioScience* 38:92-98.
- Turner, M.G., W.H. Romme, and R.H. Gardner. 1994. Landscape disturbance models and the long-term dynamics of natural areas. *Natural Areas Journal* 14:3-11.
- Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.
- Van Sickle, J. and Gregory, S.V. 1990. Modeling inputs of large woody debris to streams from falling trees. *Canadian Journal of Forest Research* 20:1593-1601.
- Wallace, J.B., J.R. Webster, and J.L. Meyer. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2120-2137.
- Webster, J.R., E.F. Benfield, T.P. Ehrman, M.A. Schaeffer, J.L. Tank, J.J. Hutchens, and D.J. D'Angelo. 1999. What happens to allochthonous material that falls into streams? A synthesis of new and published information from Coweeta. *Freshwater Biology* 41:687-705.
- Williams, J.E., J.E. Johnson, D.A. Henderson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McCallister, and J.E. Deacon. 1989. Fishes of North America, endangered, threatened, and of special concern. *Fisheries* 14(6):2-21.
- Wimberly, M.C., T.A. Spies, C.J. Long, and C. Whitlock. 2000. Simulating historical variability in the Oregon Coast Range. *Conservation Biology* 14: 167-180.
- Wipfli, M.S. and D.P. Gregovich. 2002. Invertebrates and detritus export from fishless headwater streams in southeastern Alaska: Implications for downstream salmonid populations. *Freshwater Biology* 47:957-970.
- White, P.S. and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. Pages 3-13. in S.T.A. Pickett and P.S. White, editors. *The ecology of natural disturbance and patch dynamics*. Academic Press, Orlando, Florida.
- Zimmerman, A. and M. Church. 2001. Channel morphology, gradient profiles and bed stresses during flood in a step-pool channel. *Geomorphology* 40:311-327.

